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A Guide for Incorporating AdH Modeling Data into ArcGIS® Using a netCDF: A Case Study for the Sacramento River

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PURPOSE: Expanding technology and the growing number of modeling applications has increased the need for modeling output to be easily accessible and transferable to multiple applications in a common data format. It is beneficial, therefore, for U.S. Army Corps of Engineers (USACE) research scientists to leverage application tools and information available in various software packages to improve data analysis and expand research options. The primary objective of this technical note is to provide a tutorial for the conversion, visualization, and application of Adaptive Hydraulics (AdH) modeling data in the network Common Data Format (netCDF) for use in ArcGIS®. This guide will demonstrate the suitability and use of netCDF as a standard for packaging modeling data for distribution to USACE districts and project stakeholders.

INTRODUCTION: The ability to understand, interpret, and assess hydrodynamic data is essential for USACE districts and project stakeholders as they collaborate to provide innovative solutions to USACE problems. Consequently, the integration of AdH and ArcGIS® application tools was proposed as a possible key to enhancing research capabilities. AdH is a numerical model used by the USACE to predict hydrodynamics of shallow two-dimensional channel flow environments (Winter 2013; Brown et al. 2009; and McAlpin et al. 2009). ArcGIS® is a geospatial analysis and decision support application that is widely used throughout the USACE to examine spatial relationships among various spatial datasets (Lin and Kleiss 2007; Podoski 2013; Follum 2013). Since AdH modeling data cannot be directly imported into ArcGIS®, an intermediate file format is required for compatibility with ArcGIS®, as well as with other modeling and geospatial software applications. As a result, the netCDF format was chosen for evaluation as the standard file format for packaging model data for transfer to USACE districts and project stakeholders. The netCDF files are commonly used in the scientific community for internet dissemination of modeled data (Rew et al. 2011) and are defined by University Corporation for Atmospheric Research (UCAR 2013) as “a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data.”

BACKGROUND: The USACE Sacramento District (SPK) has sponsored the development of hydrodynamic models to support ongoing levee repairs on the Sacramento River. The levee repairs are intended to maintain levee integrity and enhance in-river habitat for salmonids. Models were developed for existing conditions as well as for proposed Environmental Impact Statement (EIS) levee repair alternatives. These high-resolution models were developed by the U.S. Army Engineer Research and Development Center, Coastal Hydraulics Lab (ERDC-CHL) to provide better flow solutions for an Eulerian Lagrangian Agent Method (ELAM) fish movement model and were based on a modified version of a larger, low-resolution model

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previously developed by Dynamic Solutions, LLC (Dynamic Solutions 2011). Boundary conditions were extracted from the lower resolution model once flow conditions were updated for December 12, 2010 through March 1, 2011 and used for the high resolution models. The high resolution AdH model, representing an existing condition simulation created as part of this effort, was chosen to illustrate the procedures outlined in this document. The selected model domain spans a 20-mile reach of the Sacramento River from Knight's Landing to the Interstate 5 Bridge where several levee repair sites are proposed. The model domain also includes both the channel and the overbank areas between the levees (Figure 1). The hydrodynamic variables (acceleration magnitude, X component of acceleration, Y component of acceleration, water depth, hydraulic strain, velocity magnitude, X component of velocity, Y component of velocity, and river bottom depth) within the model were estimated at varying daily time intervals beginning on December 12, 2010 and ending on March 1, 2011. The computational unstructured mesh generated by ERDC-CHL consists of 192,467 triangular elements and 99,510 nodes (Figure 2).

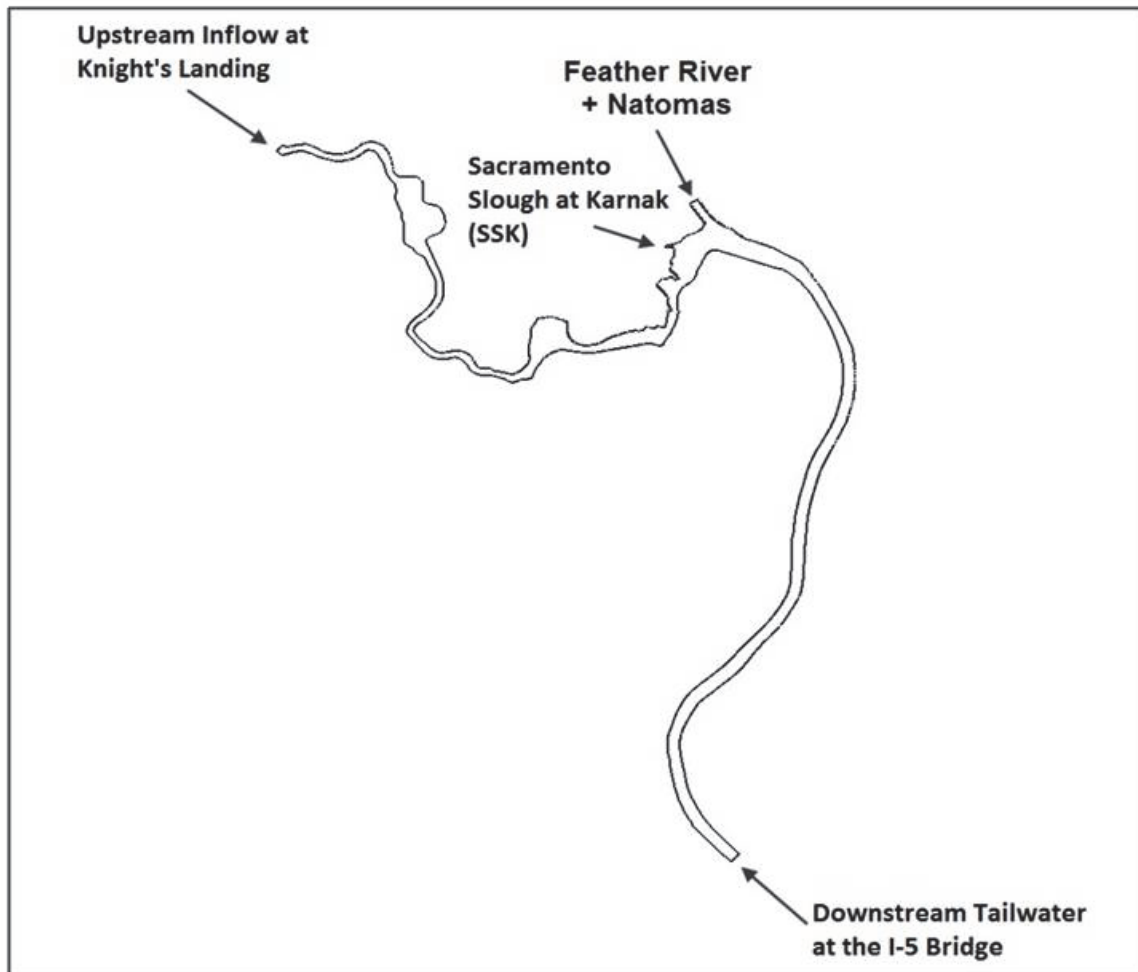


Figure 1. Flow domain of the existing Sacramento River hydraulic model.

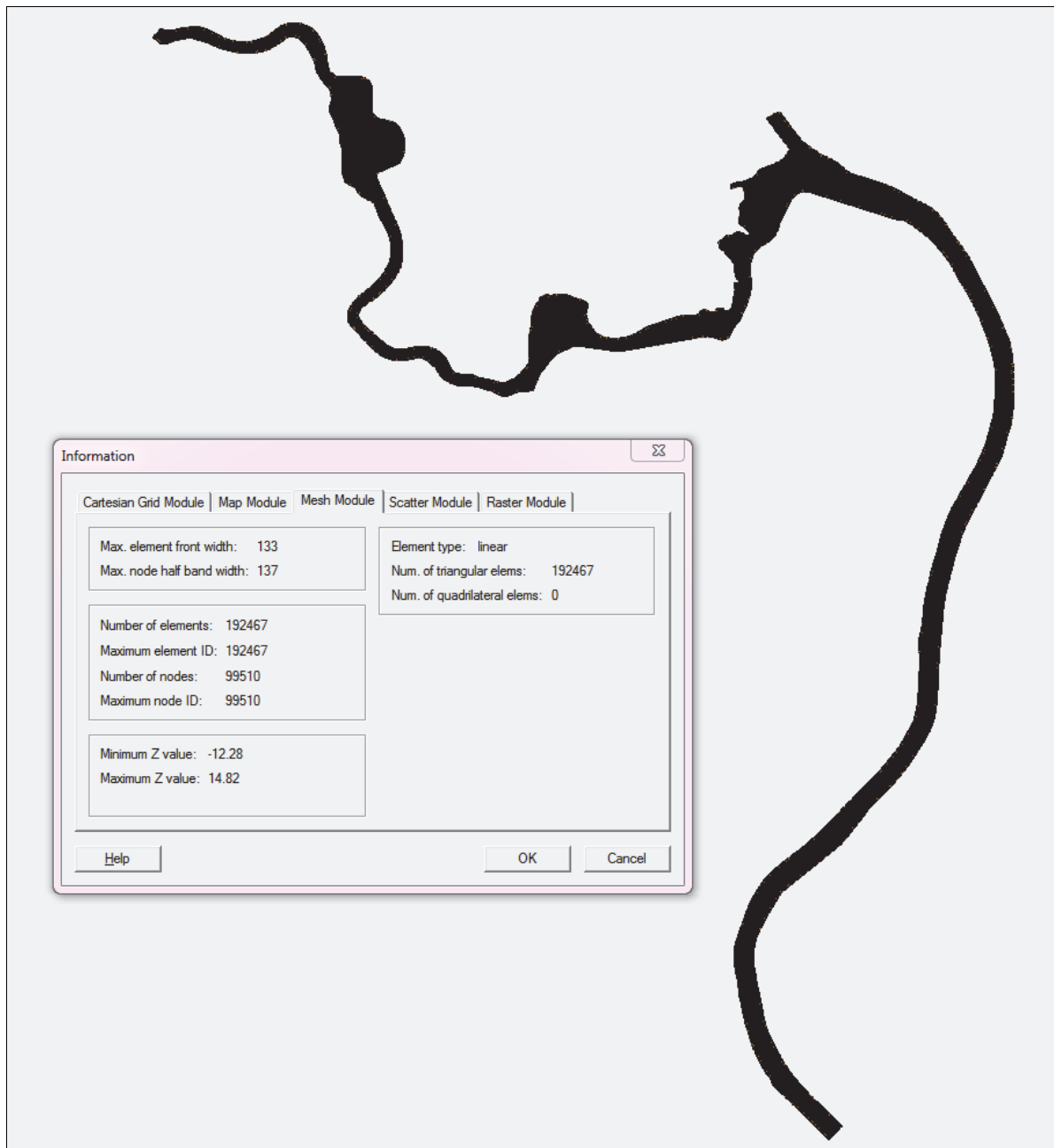


Figure 2. Sacramento River computational unstructured mesh.

METHOD: Conversion of AdH Modeling Data into netCDF File Format. Although ArcGIS® is capable of representing unstructured meshes in TIN format, this solution is extremely limited and lacks the flexibility provided by a netCDF data model. Consequently, the unstructured mesh from the existing condition simulation of the Sacramento River reach was converted into a netCDF format using the following method. First, a C# program was designed to determine the centroid of each triangle element of the unstructured mesh surface. Next, the value of each hydrodynamic parameter for each vertex of a given triangular element in the unstructured mesh was averaged and the resulting value was assigned to the output centroid point location for each triangle element. Then, all centroid point locations in conjunction with their

assigned hydrodynamic values were exported to an American Standard Code for Information Interchange (ASCII) comma delimited text file containing attributes for the X coordinate, Y coordinate, and hydrodynamic variable values, including acceleration magnitude (meters/second² or m/s²), the X and Y components of acceleration (m/s²), water depth (meters or m), river bottom depth (m), hydraulic strain (m/s/m), velocity magnitude (m/s or meters/sec), and the X and Y components of velocity (m/s). This step was repeated for each two-day time interval of the mesh surface. Finally, the text files were imported into ArcGIS® and converted to individual point shapefiles using the X and Y coordinates for each two-day time interval. Forty output shapefiles containing approximately 200,000 sampling points each were generated for the December 12, 2010 through March 1, 2011 time period.

Nine spatially continuous raster GRID surfaces were generated in ArcGIS® for each time interval by interpolating (ordinary kriging) the point features for each hydrodynamic variable. Krivoruchko (2011) defines ordinary kriging as “a statistical model which predicts the parameter values of unknown locations based on the dependence between pairs of points from examination of all similarly distant pairs in the data.” The output cell size for each GRID layer was defined as 5 meters and was determined by considering the mean distance between input points within the point shapefiles. The resulting surfaces were then clipped to the study area boundary. (Figure 3)

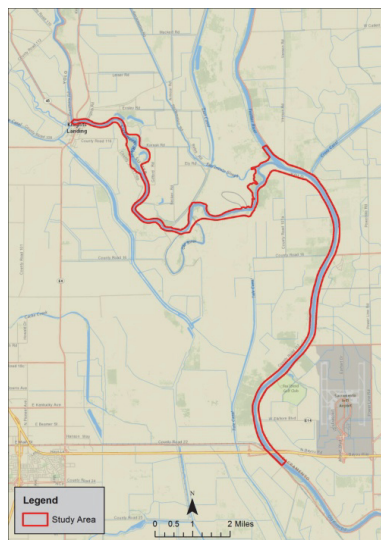


Figure 3. Sacramento River study area.

Once all raster surfaces were generated, the GRID files were converted to a netCDF file using R software programming (see Appendix for R pseudo code; R Development Core Team 2010; UCAR 2013). Each final output netCDF file contains multi-temporal raster layers representing the nine hydrodynamic variables defining acceleration magnitude, the X and Y components of acceleration, water depth, river bottom depth, hydraulic strain, velocity magnitude, and the X and Y components of velocity for the Sacramento River reach (Figure 4).

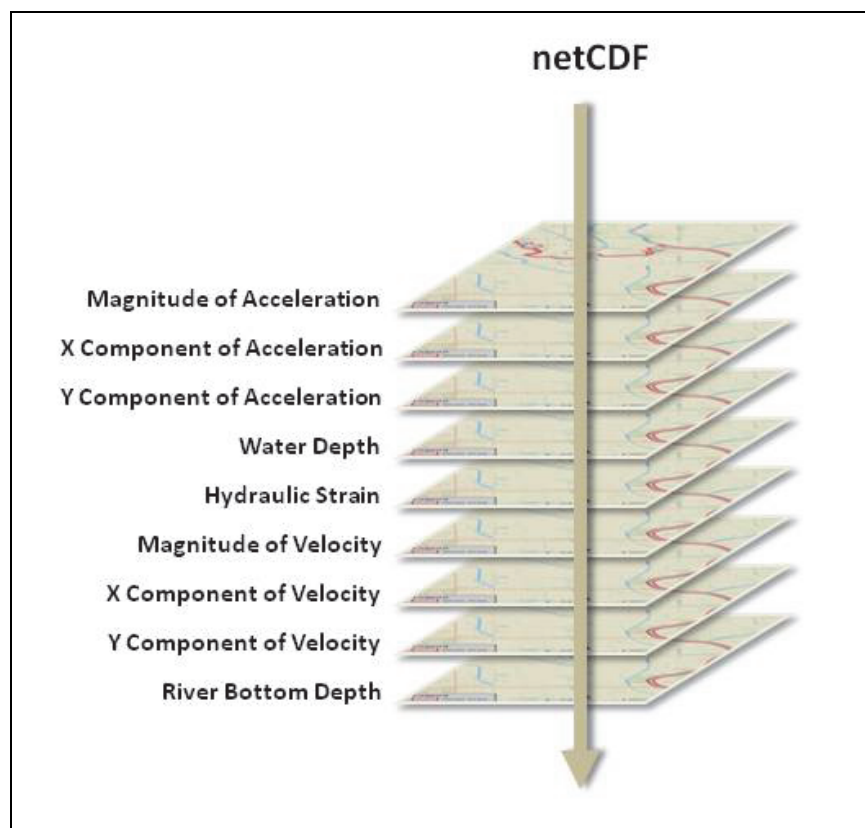


Figure 4. The netCDF file hydrodynamic data raster array for the Sacramento River.

TUTORIAL: This section will guide the reader through three steps: (1) importation, (2) symbolization and visualization, and (3) data analysis and exploration of a netCDF file through ArcGIS®.

The procedures documented in this technical note were written for compatibility with Environmental Systems Research Institute (ESRI) ArcGIS® version 10.0 software (ESRI, Redlands, CA) and Classic netCDF standard (netCDF version 3.x).

Step 1: Import netCDF File Into ArcGIS®. The following steps provide a guide for importing the netCDF file (SRv3i_8.nc) containing hydrodynamic variables for the Sacramento River reach into ArcGIS® for the December 12, 2010 to December 25, 2010 time frame. Since the ArcMap® *Add Data* function does not currently support netCDF files, the first step is to add the netCDF file by dragging and dropping the SRv3i_8.nc netCDF file from Windows Explorer into the ArcMap® *Table of Contents TOC* (Figure 5). When the file appears in the *TOC*, the layer will be named in accordance with the randomly selected variable in the netCDF file; in this case velocity.

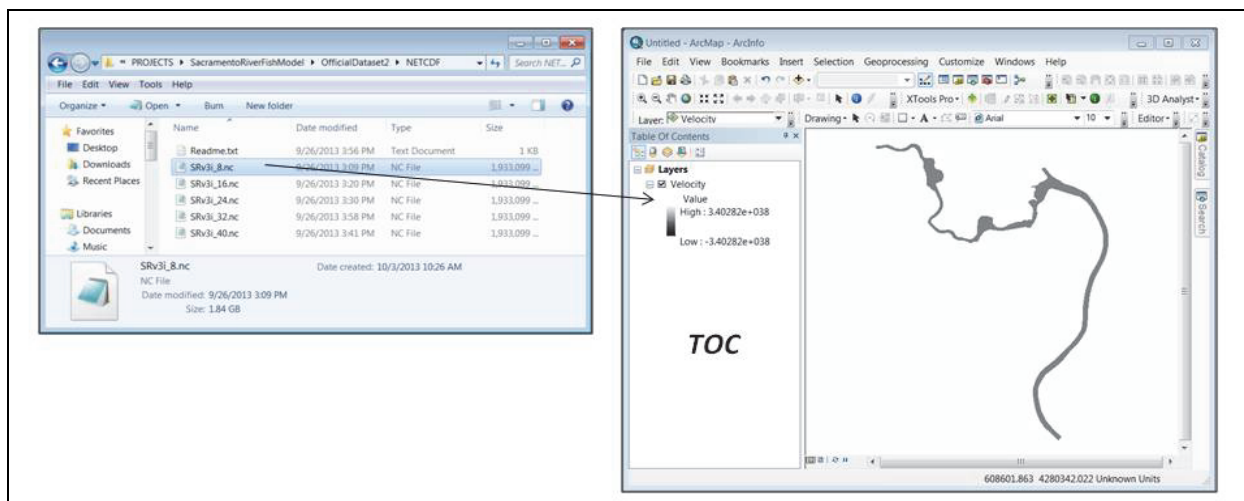


Figure 5. Drag and Drop the netCDF file into ArcMap® (ESRI 2011).

To avoid confusion when displaying variables other than velocity, the layer name should be changed to reflect a more descriptive name for the entire file, such as Sacramento Hydro. This can be achieved by right clicking the layer in the **TOC**, selecting *Properties*, and entering a new layer name under the *General* tab of the **Layer Properties** dialog box. Clicking *Apply* and *OK* will change the layer name in the **TOC** (Figure 6). Please note, the Sacramento Hydro layer is still a netCDF file, only the name has been changed.

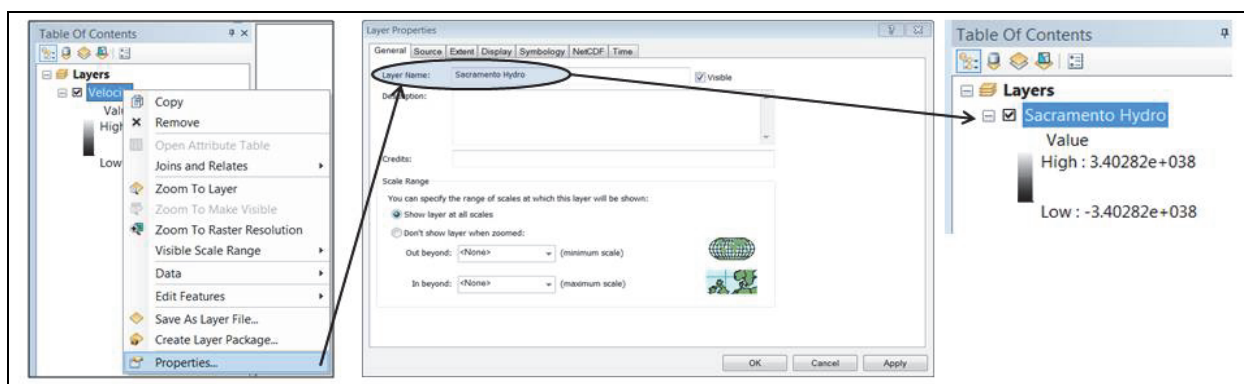


Figure 6. The netCDF layer name change (ESRI 2011).

Next, define the spatial reference for the netCDF file by clicking the **ArcToolbox** button on the Standard Toolbar and expanding the *Data Management Tools* to *Projections and Transformations*>*Raster*. Then, double click *Define Projection* (Figure 7). When the **Define Projection** dialog box appears, select the *Input Dataset* by clicking the browse button and choosing the Sacramento Hydro layer. Next, select the geographic projection system for the layer by clicking the *Coordinate System* button to open the **Spatial Reference Properties** dialog box. Next, choose the select button and the **Browse for Coordinate System** dialog box will appear. From the dialog box, choose *Projected Coordinate System*>*UTM*>*NAD 1983*>*NAD 1983 UTM Zone 10N.prj*, then click the *Add* button and OK button on the **Spatial Reference Properties** dialog box. Finally, click the OK button on the **Define Properties** dialog box to complete the layer projection definition.

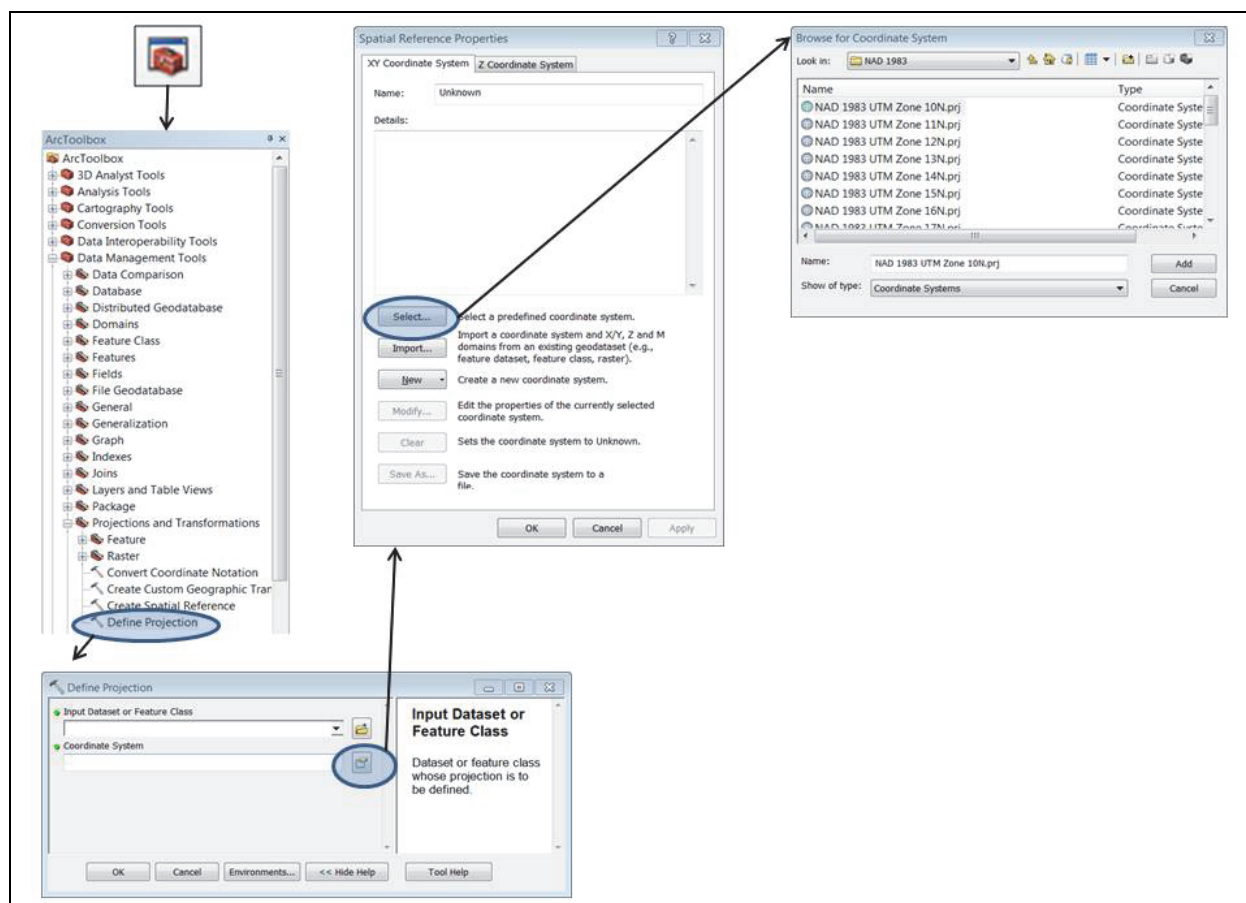


Figure 7. Defining the Projection System of the netCDF (ESRI 2011).

Since the netCDF file is comprised of multiple data layers based on hydrodynamic variables and ArcGIS® can only display one variable layer of the netCDF at a time, display parameters must be set for the netCDF file. Therefore, it is important to be cognizant of the variable layer selected for display. To verify or set the display parameters for the netCDF file, select the *netCDF* tab from within the **Layer Properties** dialog box (Figure 8).

Nine variable options are available from the pulldown list; these include the raster surfaces generated in ArcGIS® for each hydrodynamic parameter: AccelerateMag (acceleration magnitude), AccelerateX (X component of acceleration), AccelerateY (Y component of acceleration), Depth (water depth), HydStrain (hydraulic strain), VelocityMag (velocity magnitude), VelocityVectorX (X component of velocity, commonly U), VelocityVectorY (Y component of velocity, commonly V), and Zdata (river bottom depth). Two additional parameters required for correct spatial positioning of the data include the X dimension variable “Long,” representing the longitude coordinate field and the Y dimension variable “Lat,” representing the latitude coordinate field.

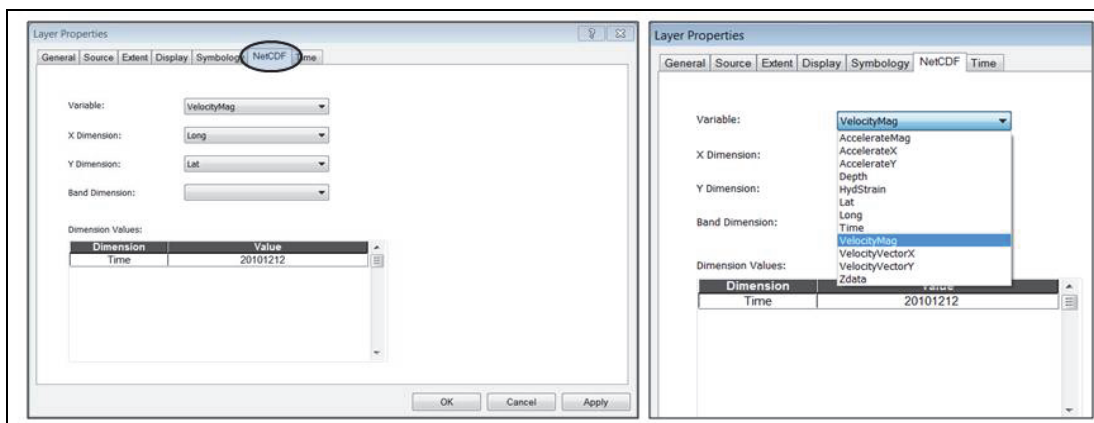


Figure 8. Set the netCDF layer properties (ESRI 2011).

Data values for each of the nine hydrodynamic variables in the netCDF file are available at a two-day time interval from December 12, 2010 to December 25, 2010. In order to access time-specific values within this range, time control needs to be enabled for the layer. This can be achieved by either selecting an exact date using the *Time Dimension* on the netCDF tab (Figure 8), or by enabling time in the *Time tab* (Figure 9). Under the *Time tab*, mark the checkbox for *Enable time on this layer*, set the time dimension equal to the Time variable, then set the temporal field format to YYYYMMDD and select the desired time step interval. Clicking the *Calculate* then *Apply* buttons on the *Time tab* with the time step interval and field formats set will enable the use of ArcGIS® time controls on the layer.

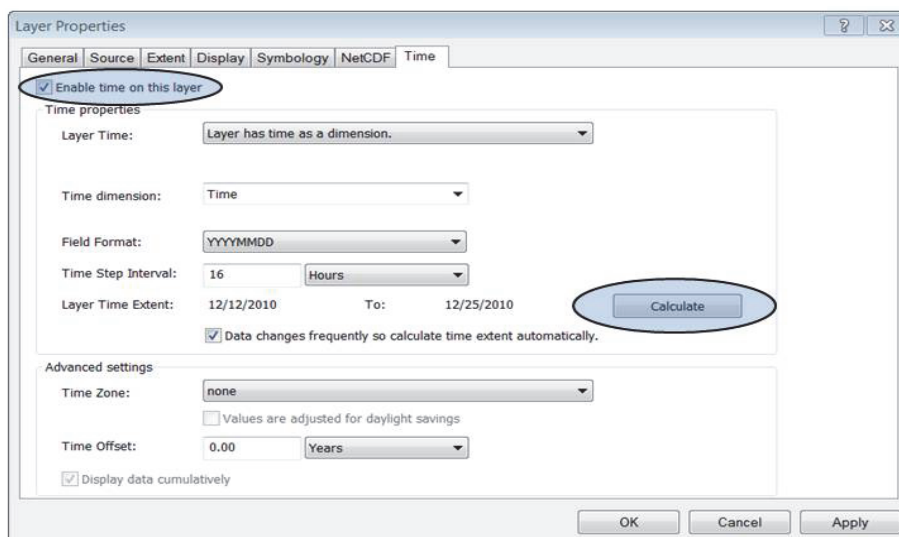


Figure 9. Set the netCDF layer time dimension properties (ESRI 2011).

An alternate method for importing the netCDF data into ArcMap® is by using *Multidimensional Tools* to select raster surfaces from the netCDF file based on the desired variable and temporal range. The selected raster surfaces can then be saved into a raster layer file and added to the **TOC**. To create the layer, click the *ArcToolbox* button from the Standard Toolbar (Figure 10). Expand the *Multidimension Tools* toolbox and select the *Make netCDF Raster Layer* to open the

dialog box. Select the browse button and navigate to the netCDF file (SRv3i_8.nc). Next, from the dropdown menus, select the variable of interest (in this case VelocityMag); the X and Y dimensions, which are the longitude coordinate and latitude coordinates, respectively; the dimension value (in this case Time); then, specify the name of the output raster layer (Velocity_Layer). Click the *OK* button to create the raster layer (Velocity_Layer) and add it to the *TOC* in ArcMap® (Figure 11).

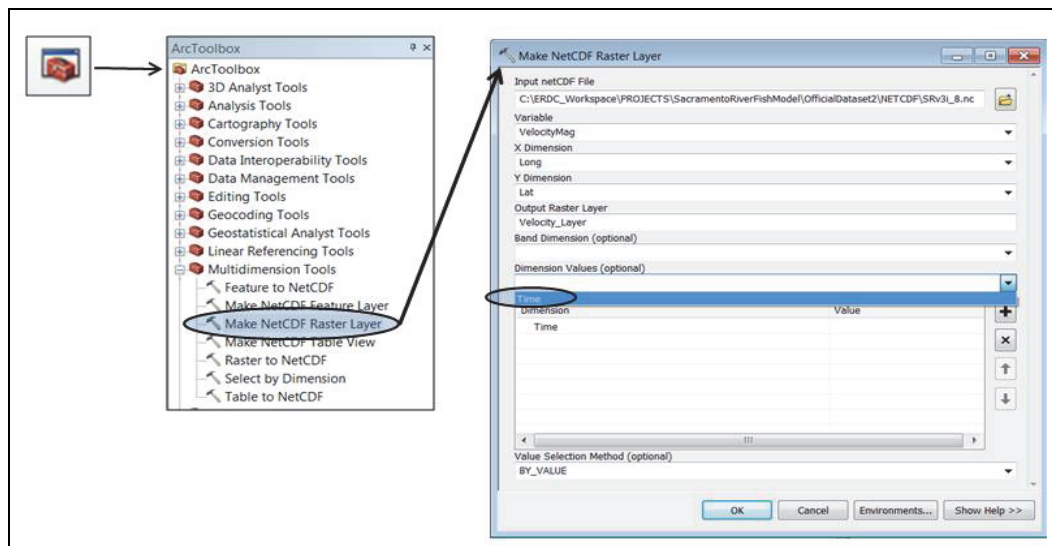


Figure 10. Set parameters to create a new raster layer based on a netCDF variable (ESRI 2011).

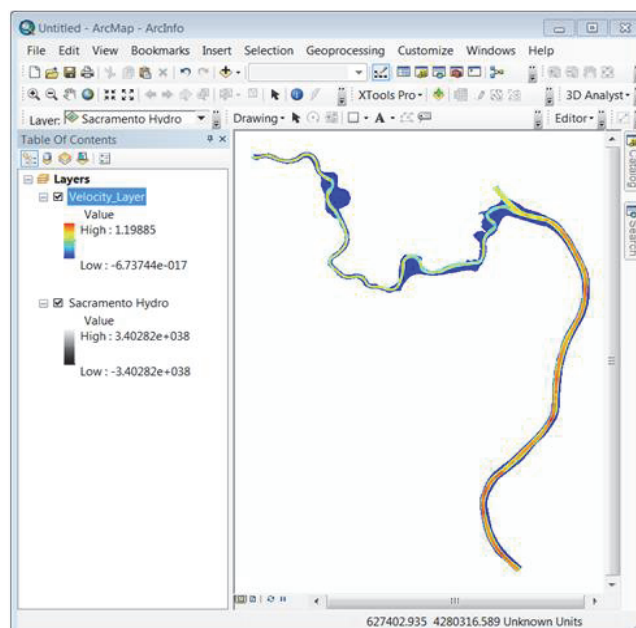


Figure 11. Raster layer added to the table of contents in ArcMap® (ESRI 2011).

Step 2: Data Symbology and Visualization. In order to display the Sacramento River hydrodynamic data values in an easily understandable format, appropriate data symbology must be selected. The netCDF raster layers are based on continuous data values and therefore are displayed in ArcMap[®] by calculating a histogram, which represents the number of times a range of values occurs within the dataset. Colors are then applied to the data range. For example, to display the water depth range of the Sacramento River, first set the display parameters for the netCDF file by right clicking the layer (Sacramento Hydro) in the **TOC** and selecting **Properties** from the menu option (Figure 12). The **Layer Properties** dialog box will appear. Choose the **netCDF** tab and select the depth as the variable, the “Long” variable for the X dimension, the “Lat” variable for the Y dimension, the time dimension value desired, and then click **Apply**.

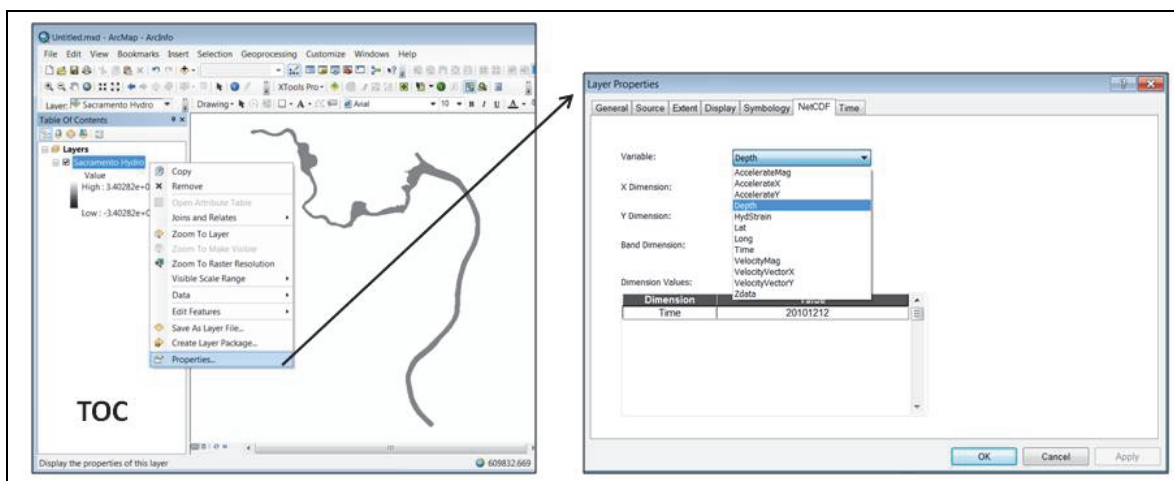


Figure 12. Set the netCDF layer properties for the depth variable (ESRI 2011).

Next, select the **Symbology** tab from the **Layer Properties** dialog box and display the image as stretched using the **Custom** option under **Stretch Type** (Figure 13). ArcMap[®] will automatically request that histogram statistics be recomputed. If not, statistics can be manually created by choosing the **Histogram** button located adjacent to the **Stretch Type**.

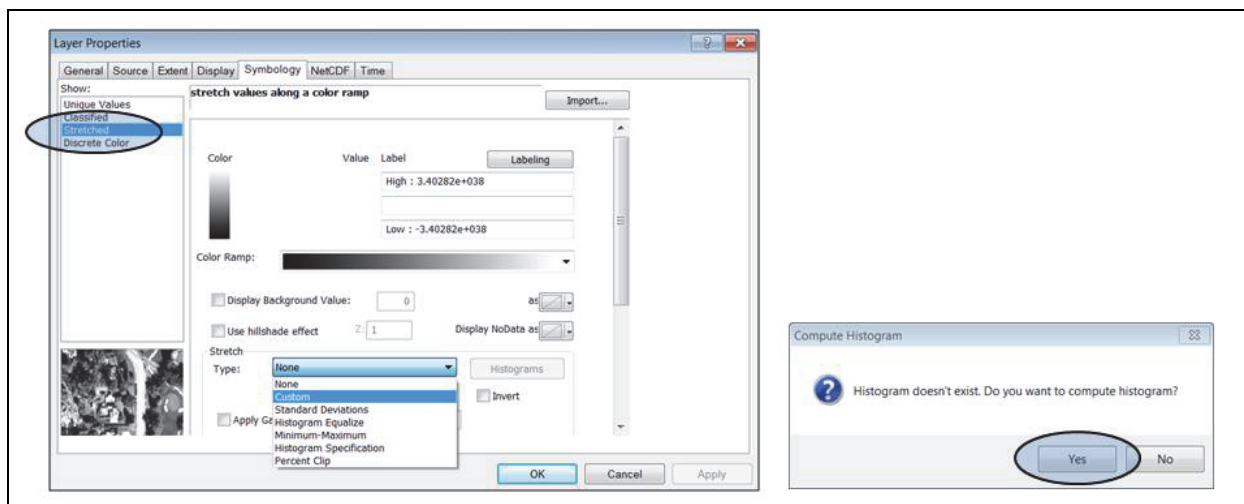


Figure 13. Compute histogram statistics for the netCDF layer (ESRI 2011).

Note the change in label values after the histogram statistics have been calculated (Figure 14). The dataset can then be symbolized using the color ramp pulldown menu. Since the Sacramento River netCDF is based on multiple data parameters, a histogram needs to be computed every time a different variable is selected so that the data is properly displayed in the view frame.

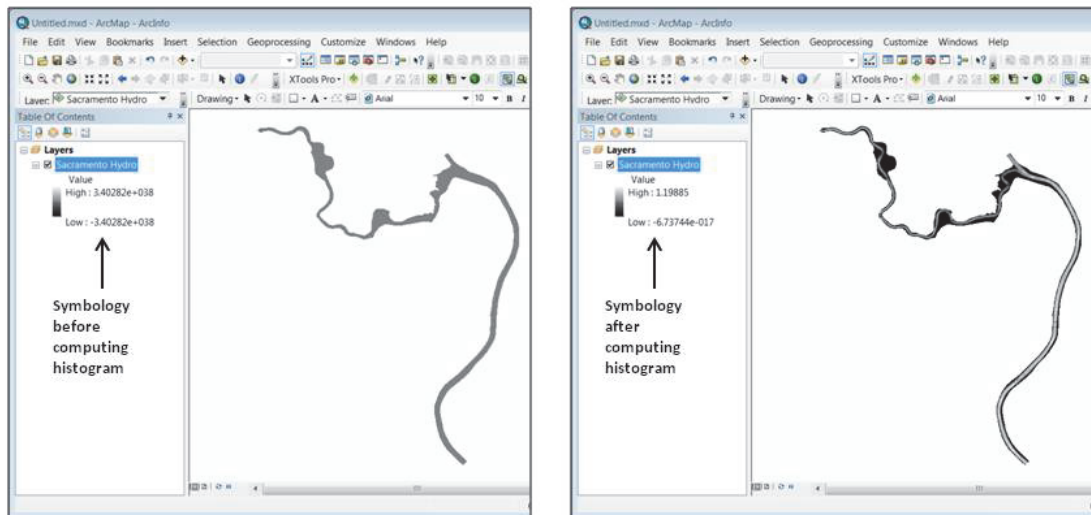


Figure 14. Change in label values of the netCDF file before and after histogram computation (ESRI 2011).

If an alternate classification scheme is desired, the variable data from the netCDF file must first be converted to an individual raster layer. To export the water depth raster as a separate layer, right click the Sacramento Hydro netCDF layer in the **TOC** and select **Data>Export Data** (Figure 15). Select **Raster Dataset (Original)** for both the raster extent and spatial reference, and set the cell size to 5 by 5. Next, browse to the directory location to save the new raster file and define the output raster layer name; in this case, it will be called RiverDepth; click **Save**. The raster layer (RiverDepth) will be created, and added to the **TOC** in ArcMap®.

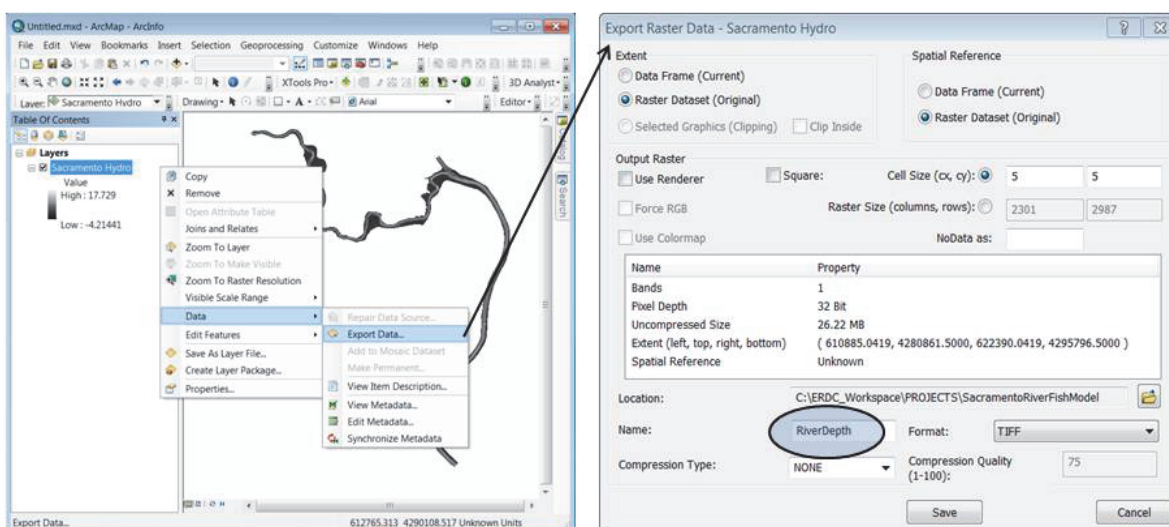


Figure 15. Exporting the netCDF file as an ESRI raster GRID (ESRI 2011).

Once the data has been converted to a separate layer, an alternative symbology scheme can be applied. For this example, the water depth raster will be classified to display depth values in equal intervals based on the minimum and maximum values of the dataset. First, right click the RiverDepth raster layer in the **TOC** and select **Properties** to open the **Layer Properties** dialog box (Figure 16). Next, choose the **Classified** option under the Symbology tab and then select the **Classify** button. This selection will open the **Classification** dialog box, which will allow the user to establish the classification method to provide the specific breaks preferred for display. In this case, choose the **Equal Interval** classification method and click OK. Color values can now be added to the layer by selecting the desired Color Ramp from the **Layer Properties** dialog box.

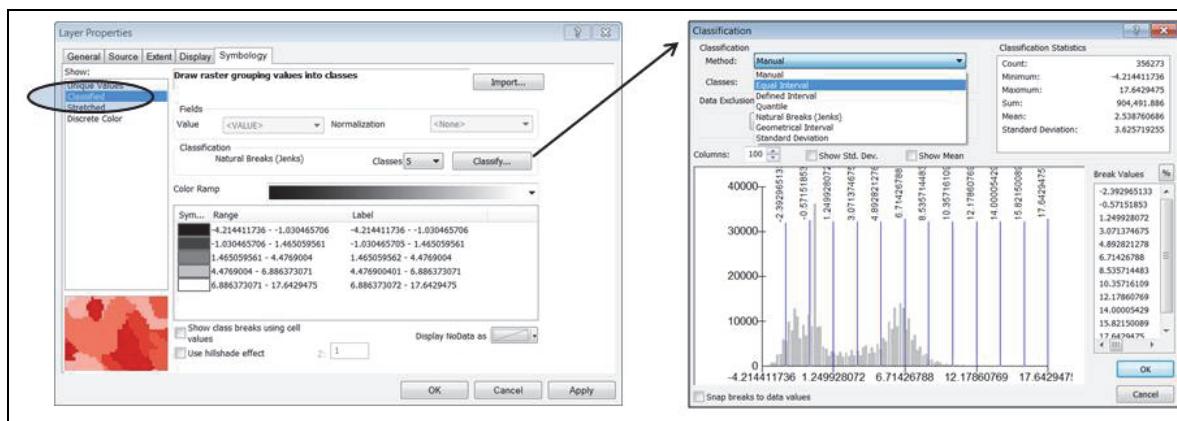


Figure 16. Classify water depths using equal interval classification (ESRI 2011).

If a data inquiry is required to display river depths between 4.1 to 7 meters, the **Exclusion** button on the **Classification** dialog box can be used to exclude the undesired values from the display; in this case, value ranges from -4.5 to 4 and from 7.1 to 18 (Figure 17). Please note the **Exclusion** tool will not remove the data from the file, only from the display. Figure 18 contrasts the results between the image on the left, which displays all values in the dataset, and the image on the right, which demonstrates the excluded values.

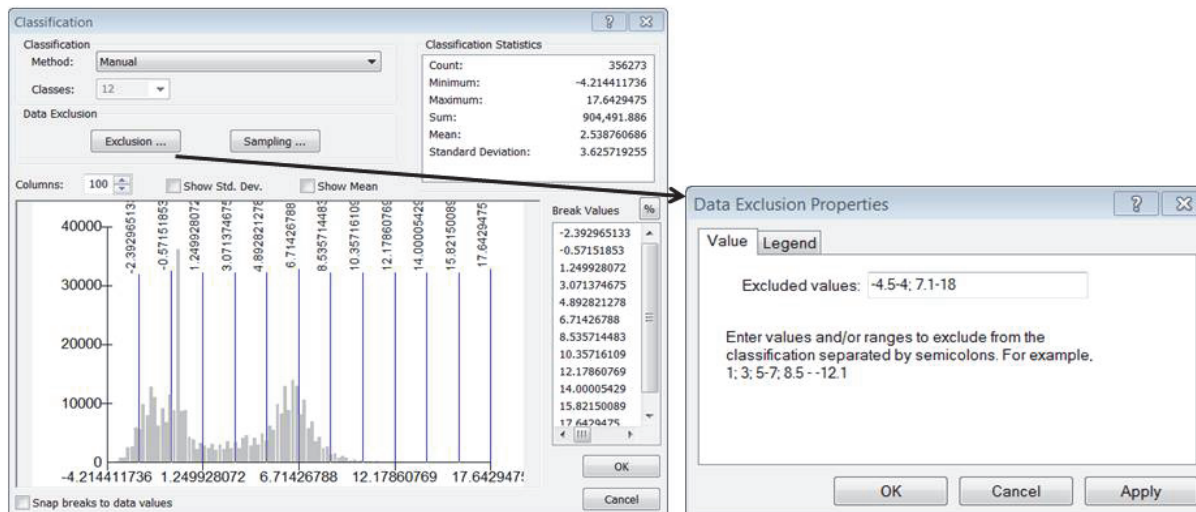


Figure 17. Classification of the Sacramento River water depth layer with exclusion of values (ESRI 2011).

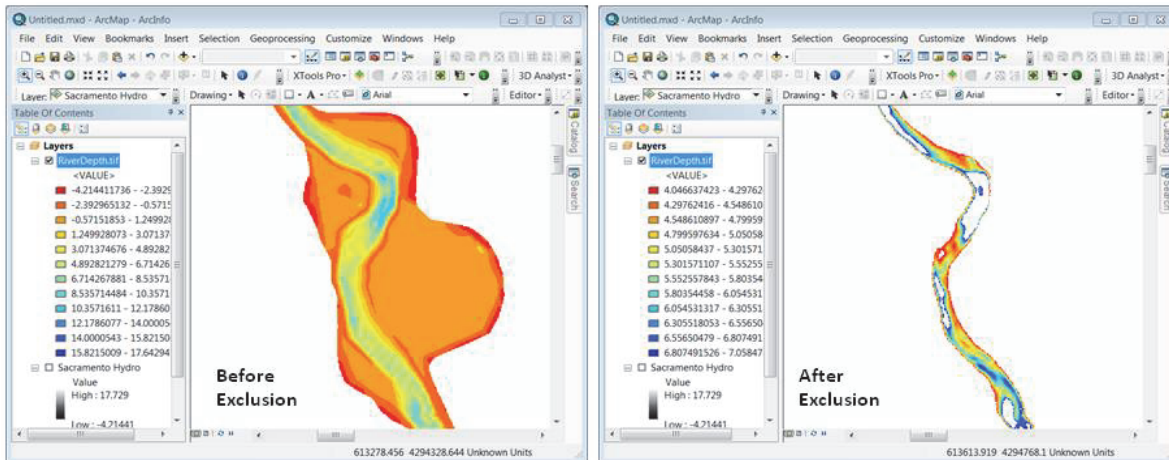


Figure 18. Classification of the Sacramento River water depth before and after value exclusions (ESRI 2011).

The netCDF hydrodynamic parameters can also be visualized through animation using the time dimension of the dataset. To view the magnitude of velocity data (Velocity_Layer) through a series of time steps, from December 12, 2010 through December 25, 2010, time must be enabled on the Velocity_Layer using the same methods and parameters as displayed in Figure 10. Once time has been enabled on the layer, the **Time Slider tool** can be utilized to animate the data through the available temporal range. To create the animation, first select the **Tools** toolbar by selecting **Customize** from the main ArcMap® pulldown menu, selecting *Toolbars*, then clicking the checkbox next to *Tools*. The **Tools toolbar** will appear (Figure 19). To open the time slider window, choose the *time slider tool* button from the **Tools toolbar**. Next on the **Time Slider Window**, choose the *Enable time on map* button (Figure 20). To select the temporal range for animation, click the *Options* button on the **Time Slider Window** to open the **Time Slider Options** dialog box and select the *Time Extent* tab. Select the Velocity_Layer from the pulldown menu to restrict the full-time extent to that layer. This will automatically populate the start and end times based on the Velocity_Layer. Click *OK* to return to the **Time Slider Window**. Select the play button to animate the velocity magnitude data from the December 12th to December 25th time series. The animation can also be exported to a file by clicking the *Export Animation* button from the **Time Slider Window**.

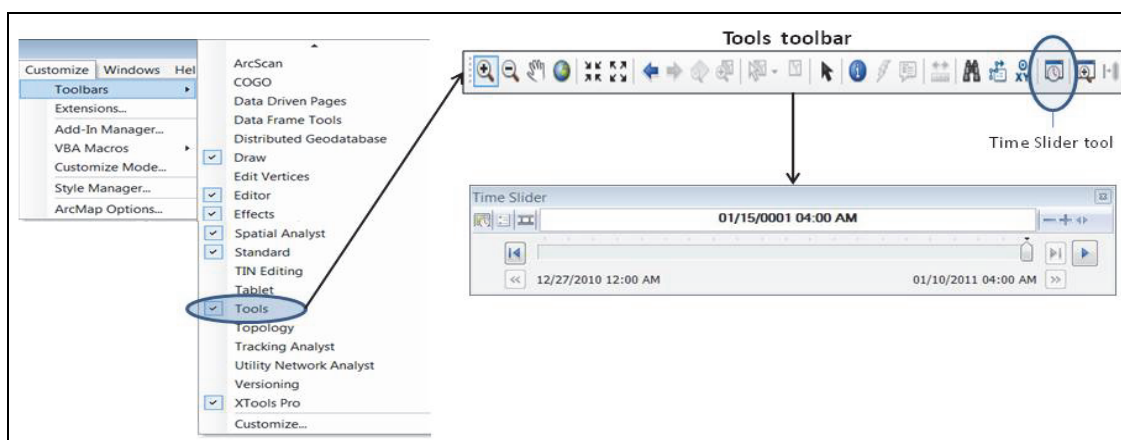


Figure 19. Opening the Time Slider Window (ESRI 2011).

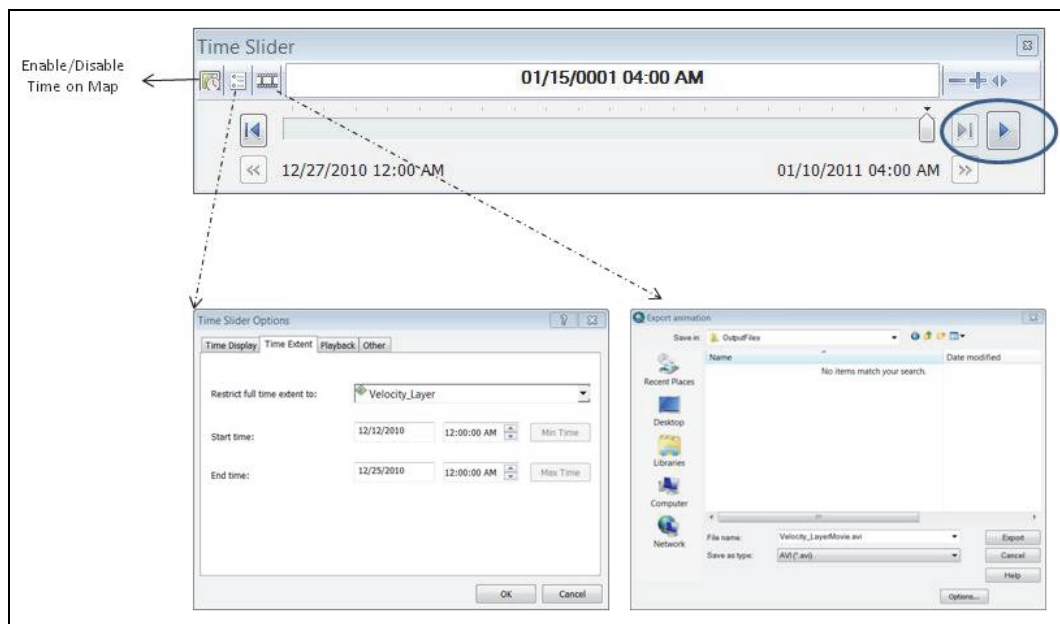


Figure 20. Visualizing time series data and exporting to an animation file (ESRI 2011).

Step 3: Data Exploration and Analysis. A hypothetical research scenario will be utilized to demonstrate the functionality of ArcGIS® for data exploration and analysis of the netCDF file. In this hypothetical scenario, researchers want to investigate the environmental variables affecting fish habitat utilization during a low-flow event within the Sacramento River reach. This example will guide the user through three analyses: (1) identifying locations, (2) generating river cross-section profiles, and (3) creating contours. ArcGIS® Spatial Analyst and ArcGIS® 3D Analyst Extensions are required for these analyses.

Analysis 1: Location Identification

If researchers wanted to identify the hydrodynamic parameters preferred by a particular fish species during a low-flow event, assuming a point layer exists which represents the spatial location of the fish species during the low-flow event, the hydrodynamic values can be identified and extracted from the netCDF files for each fish location. Please note this analysis requires the *Spatial Analyst Extension in ArcGIS®*. For this exercise, the Sacramento River water depth will be extracted for all fish locations in the Sacramento River study area. Two datasets will be needed for this exercise: first, the netCDF file, Sacramento Hydro representing water depths from the previous exercise; and second, a point file of hypothetical fish locations (HypotheticalFishLocations.shp). With both datasets added to the **TOC**, select *Spatial Analyst Tools>Extract>Extract Values to Points* from the ArcToolbox (Figure 21). The **Extract Values to Points** dialog box will appear. Define the input point features as HypotheticalFishLocations.shp, the input raster as Sacramento Hydro, and the output shapefile as RiverDepthOfFishLocations. The resultant output file contains the fish location point features along with the attribute values of the water depths. If multiple hydrodynamic variables are required, then the *Extract Multi Values to Points* tool can be applied to combine multiple layer information into the point file. However, this option requires that each netCDF raster layer be converted to a separate raster layer prior to initiation of the tool.

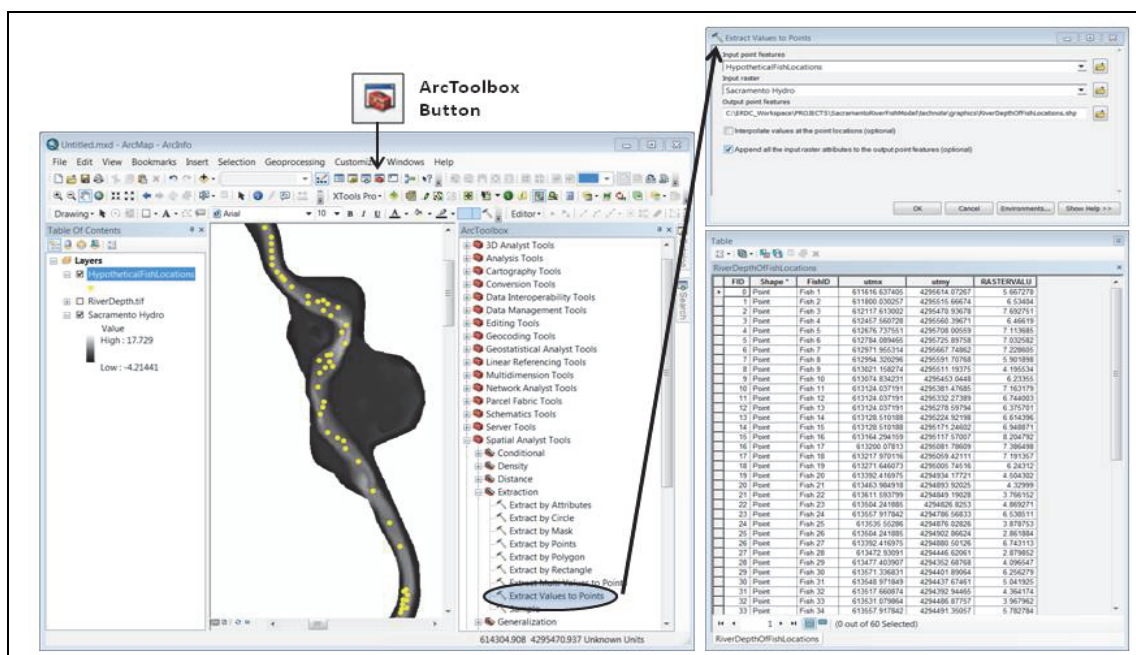


Figure 21. Extract river depth values based on fish location points (ESRI 2011).

Analysis 2: Cross Section Profile Generation

River channel cross section profiles based on bathymetric information are useful for fisheries research to better understand river channel morphology and flow dynamics. In this hypothetical low-flow event, a sample water depth profile will be generated in an area where multiple species were located to analyze the channel configuration.

Please note this analysis requires the *ArcGIS® 3D Analyst Extension*. Cross-section profiles are generated using the *3D Analyst extension*. To add the extension, select *Customize* from the *ArcMap®* pulldown menu, then select *Extensions* to open the **Extensions** dialog box and place a check mark in the *3D Analyst* box. Next, select *Customize>Toolbars* and then add a checkmark in the box next to 3D Analyst to activate the extension. The **3D Analyst** toolbar will be added to *ArcMap®* as displayed in Figure 22.

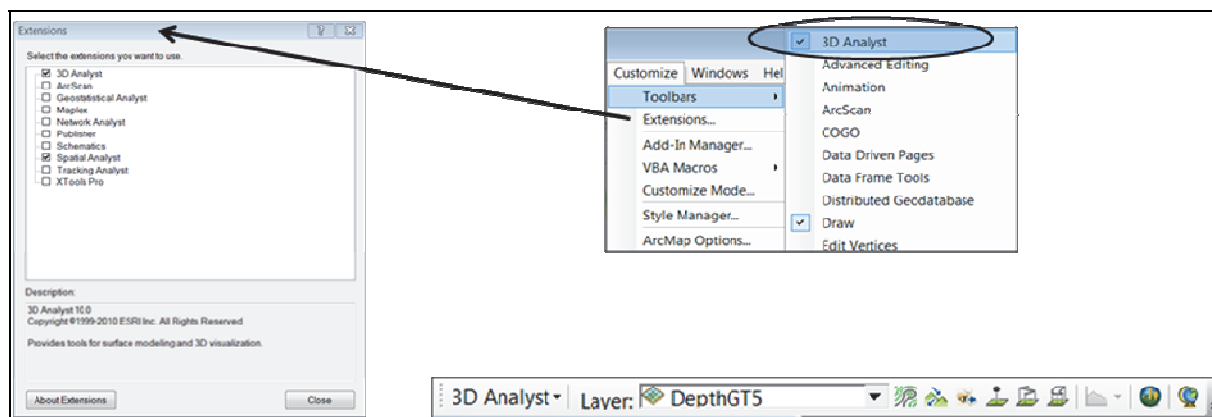


Figure 22. Activation of the *ArcGIS® 3D Analyst extension* *ArcMap®* (ESRI 2011).

The Sacramento Hydro netCDF raster representing water depth will be used to generate a cross section profile graph at a specified location of the Sacramento River. First, select the *Interpolate Line* tool from the **3D Analyst** toolbar, and draw a line across the river channel at a desired location (Figure 23).

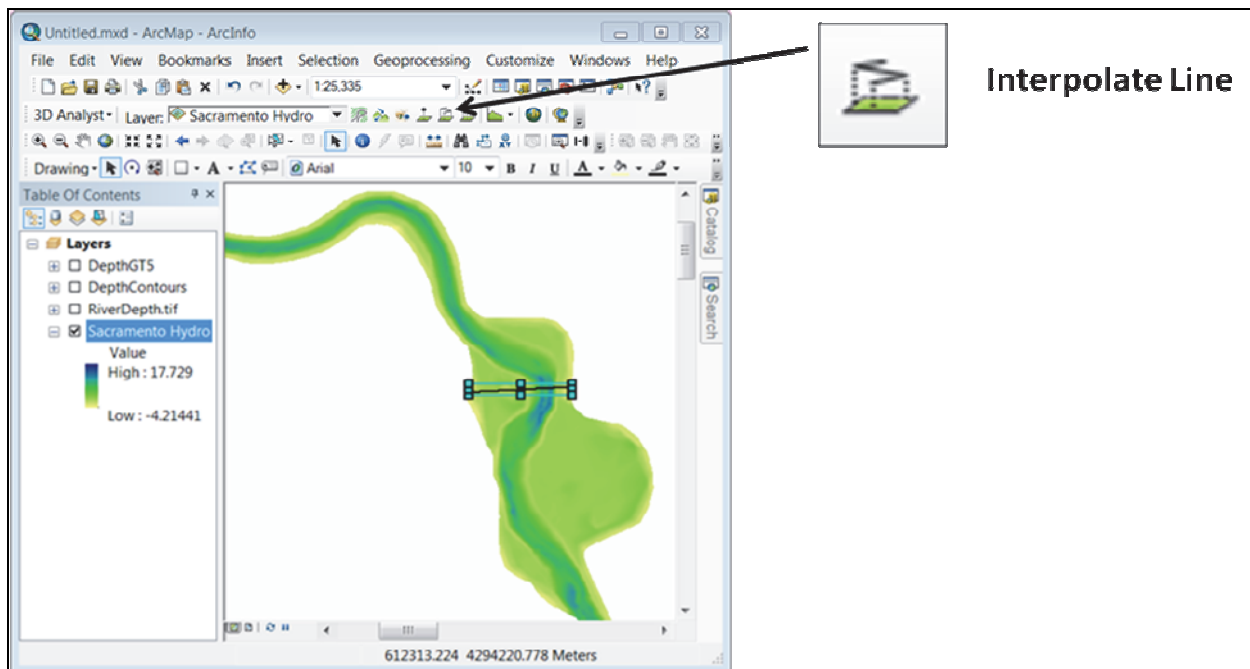


Figure 23. Use of the Interpolate Line tool to define location of the river profile for the Sacramento River (ESRI 2011).

With the line selected, choose the *Create Profile Graph* button on the **3D Analyst** toolbar (Figure 24). An inset window will appear containing the river profile graph representing the channel configuration of the drawn line.

Right click the profile graph to open the *Advanced Properties* dialog box (Figure 25). The appearance of the graph can be modified by inverting the graph, altering the axis information, and adding labels and titles. Additionally, there are available options to insert the graph into a map layout.

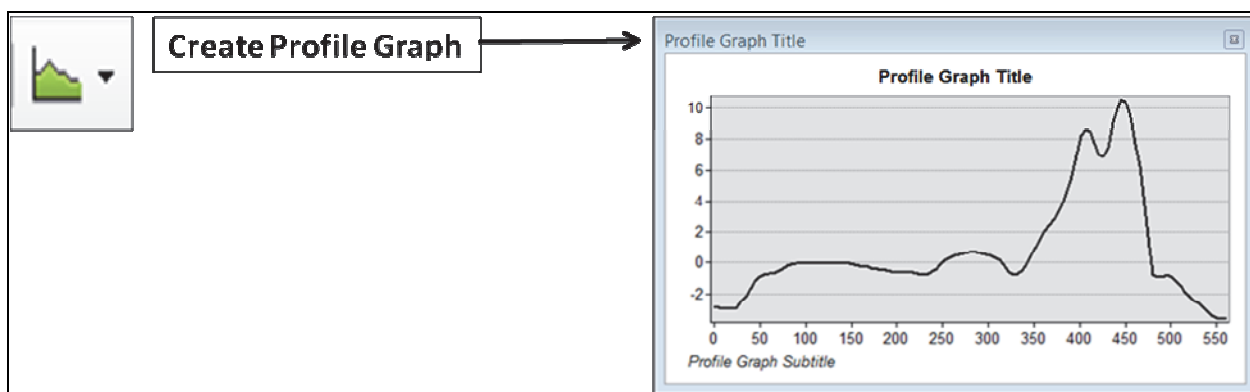


Figure 24. Create a profile graph of water depths in the Sacramento River (ESRI 2011).

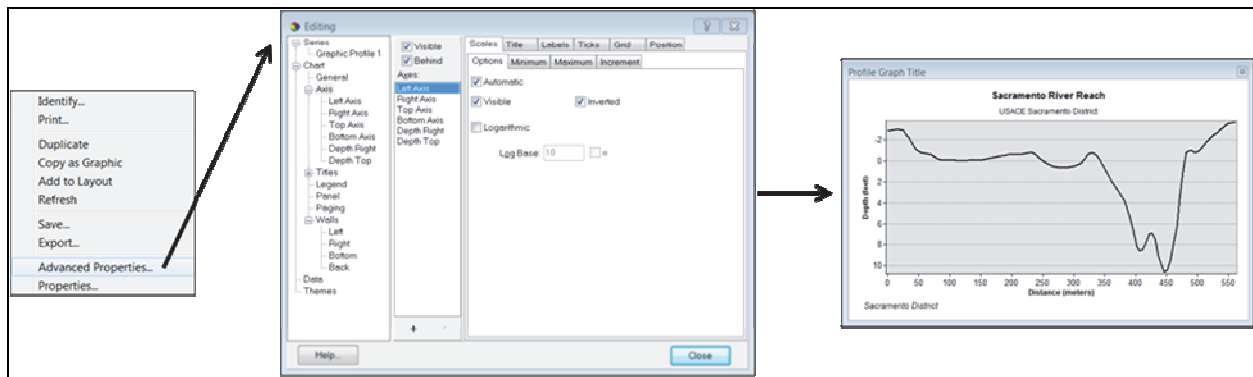


Figure 25. Modify the appearance of the profile graph (ESRI 2011).

Analysis 3: Contour Creation

Suppose that fisheries managers are concerned with the effects of hydrodynamics on a fish species during a low-flow event, and the results from the previous *Extract Values to Points* analysis demonstrates that the majority of the fish in the low-flow event preferred habitat water depths greater than 5 meters: bathymetric line features of those areas can be generated to enhance the focus of further research. Please note, this analysis requires **the ArcGIS® 3D Analyst Extension**. To accomplish this task, the *Extract by Attributes* tool located in **ArcToolbox>Spatial Analyst Tools>Extraction** will be used to extract water depths that are greater than or equal to 5 meters (Figure 26 and 27). Select the Sacramento Hydro layer as the *Input raster*, enter “value >=5” in the *Where clause* query box, and specify “DepthGT5” as the *Output raster* (Figure 26).

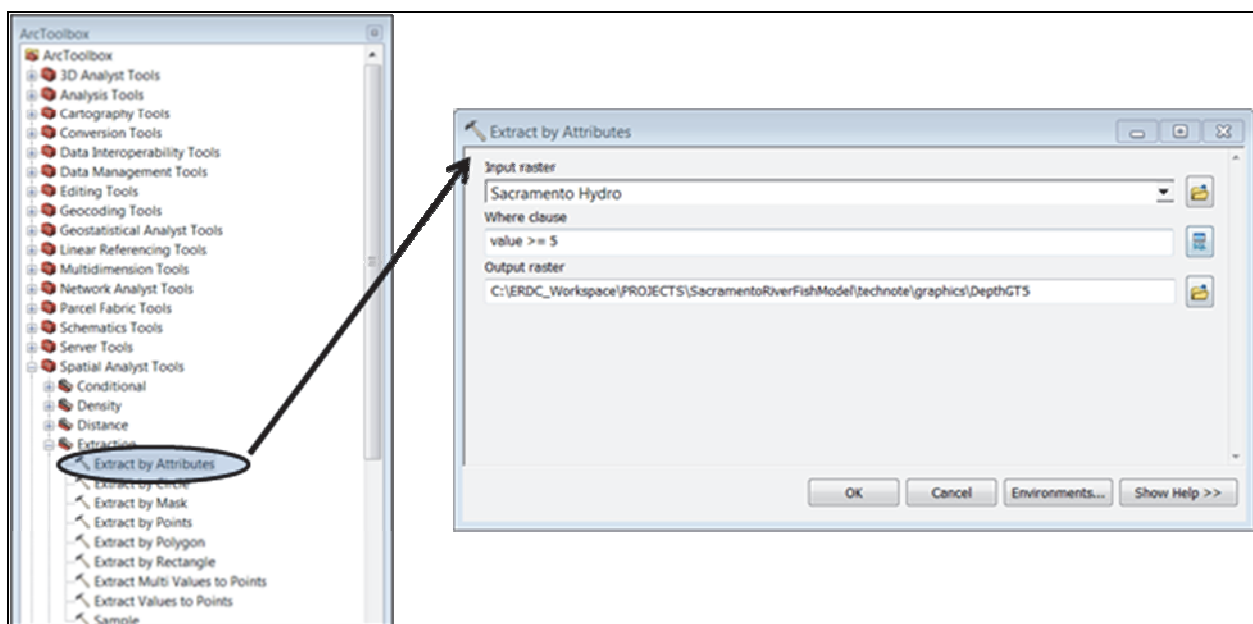


Figure 26. Create a new raster layer by extracting only specified water depth values (ESRI 2011).

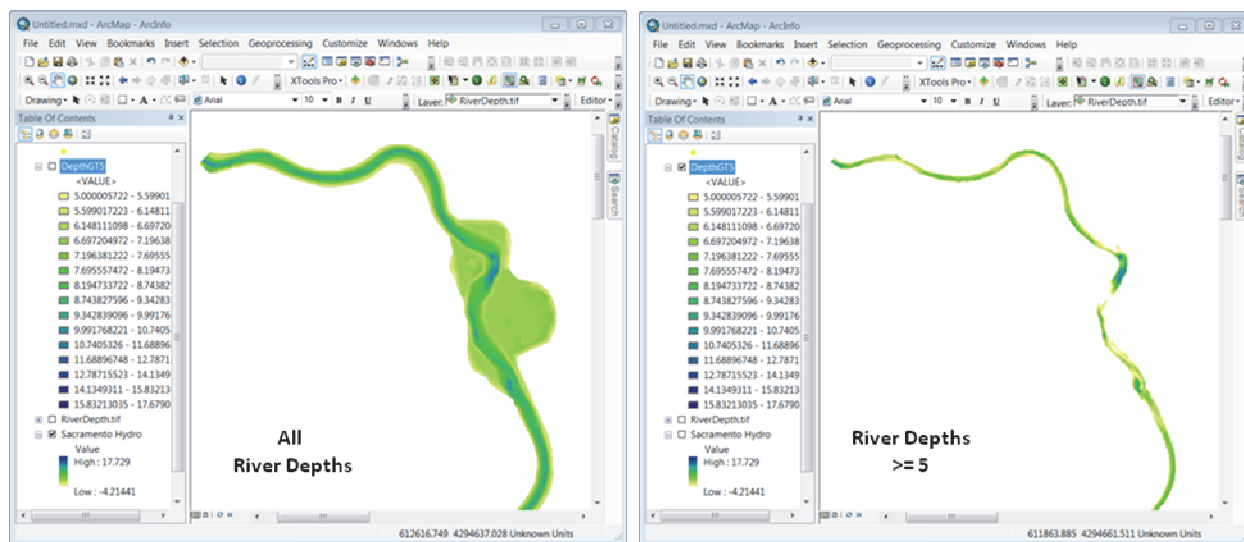


Figure 27. Raster layers before and after extraction of water depth values (ESRI 2011).

Next, bathymetric contour lines will be generated from the newly created DepthGT5 raster. This will be accomplished by using the **Spatial Analyst Tools>Surface>Contour** tool. In the **Contour** dialog box, browse to the input raster, DepthGT5 (Figure 28). Next, select the location and enter the name of the output shapefile, DepthContours.shp. Set the contour interval to 1 meter and the base contour to 5 meters. The resulting output file will contain water depth isolines representing one meter intervals starting at the base 5-meter contour line. Add symbology to the layer by right clicking the DepthContours.shp layer and selecting **Properties** to open the **Layer Properties** dialog box. Select **Unique Values** from the **Categories** option under the **Symbology** tab and choose **Contour** as the **Value Field**. Next, select **Add all Values** button to display all contour line intervals as shown in Figure 29.

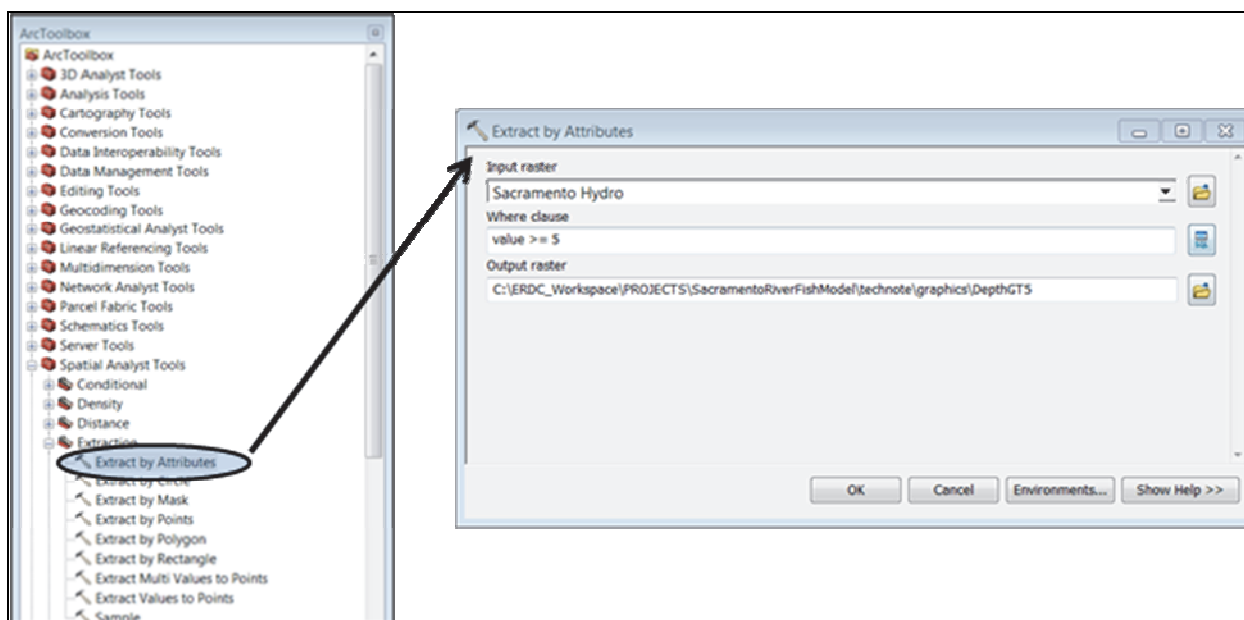


Figure 28. User-defined parameters for creating Sacramento River water depth contours (ESRI 2011).

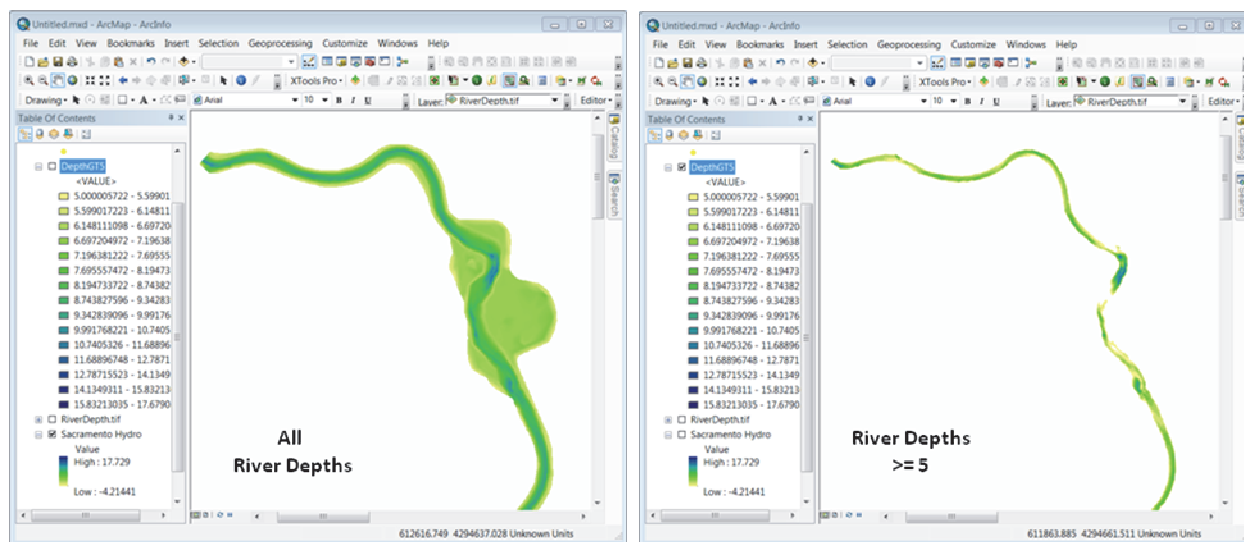


Figure 29. Symbolization of Sacramento River water depth contours (ESRI 2011).

Multiple data layers representing features such as the navigation structures, dams, non-point and point source pollution areas, navigational obstructions, surrounding vegetative habitat, dredging locations, and recreational areas can then be superimposed on the contoured area to further explore their spatial relationships.

SUMMARY: The netCDF file format (Classic netCDF standard version 3.x) is supported by several modeling applications and allows for an efficient method for packaging AdH modeling data for use in ArcGIS®. The data is easily imported for visualizations and available for use with raster tool applications in ArcGIS®. However, the large netCDF file size can cause delayed refresh rates and prolonged analysis durations. In addition, though multiple variable raster surfaces are contained within the netCDF file structure, only one may be displayed at a time. Therefore, visualizations and analysis requiring more than one surface layer must be exported to a standard ArcGIS® raster format prior to utilization, or multiple instances of the netCDF file must be added to the **TOC**. Lastly, the data layer name displayed in the **TOC** for a netCDF layer does not reflect the current variable surface layer selected for display, which can lead to uncertainty and possible inaccurate assumptions of the data. A resolution to this deficiency would be to provide scripts or extensions, which would automate a layer name change at that instant the variable parameter is selected for display.

Additional ArcGIS® applications using the netCDF should include the use of a temporal data dimension to produce animations of riverine ecosystem processes, evaluate variations in river property parameters over time, and investigate the relationship between hydrodynamic variables. It is also suggested that spatially explicit tools be developed to automate data display and analysis based on user-provided input parameters and to automate the creation of the netCDF file from AdH model output. Enhanced knowledge and distribution of modeled ecosystem data is achieved by the integration of models and geospatial technology using the standard netCDF file format.

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Scientist (EL); and David L. Smith, Research Ecologist (EL) of the U.S. Army Engineer Research and Development Center. For additional information, please consult David L. Smith, Research Ecologist, at David.L.Smith@usace.army.mil. This technical note should be cited as follows:

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NOTE: *The contents of this technical note are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such products.*

APPENDIX

Sample Psuedo R code for Converting ESRI GRID data into netCDF format (R Development Core Team, 2010 and UCAR, 2013):

```
# load the libraries
library(sp)
library(raster)
library(rgdal)
library(ncdf)

DIR_PATH <- "E:\\SacramentoRiver"
MISSING_VALUE <- -9999 # missing value
nc_output_path <- "E:\\SRv3i_TimeIndexValue.nc"

# build list of netCDF variables based on file system
# assumes variables are in individual folders in DIR_PATH
# and that those folders are named for each variable
DIR_NAMES <- list.dirs( DIR_PATH, full.names = FALSE, recursive = FALSE)
VARS <- c()
for(name in 1:length(DIR_NAMES)) {
  VARS[name] <- unlist(strsplit(DIR_NAMES[name],'/'))[2]
}
# build list of timesteps
# prefixes are the raster grid prefix names for each raster
# before the timestamp in the raster name
temp_Dir_List <- list.dirs(DIR_NAMES, full.names = FALSE, recursive=FALSE)
timeStamps <- c()
varPrefix <- c()
ix1<-1
ix2<-1
for(tempDir in 1:length( temp_Dir_List)) {
  tail <-unlist(strsplit(temp_Dir_List[tempDir],'/'))[3]
  tailNo <- as.numeric( gsub('[a-zA-Z]',"", tail ))
  prefix <- gsub('[0-9]',"",tail)
  ifelse(is.na(prefix), ix1<-ix1-1, ifelse(prefix!="info", varPrefix[ix1]<-prefix, ix1<-ix1-1))
  ifelse( is.na(tailNo), ix2<-ix2-1, timeStamps[ix2]<-tailNo)

  ix1<-ix1+1
  ix2<-ix2+1
}
# ignore the info directory
# In classic netCDF only 8 timesteps may be represented in this dataset.
# netCDF4 may provide enhanced capability.
timeStamps <- sort(unique( timeStamps ))[ 1:TimeIndexValue]
varPrefix <- unique( varPrefix )

# format the timeStamps for the netCDF control in ArcGIS®
ts<-c()
d<-as.Date("2010-12-12")
for(t in 1:length(timeStamps)) {
  dateval <- d+(as.numeric(timeStamps[t])/86400)
  ts[t] <- as.numeric(format( dateval, format="%Y%m%d"))
}
# get spatial domain
spatialExtent <- raster(temp_Dir_List[1])
LonVector = seq(xmax(spatialExtent), xmin(spatialExtent), length=ncol(spatialExtent))
LatVector = seq(ymax(spatialExtent), ymin(spatialExtent), length=nrow(spatialExtent))

# define netCDF dimensions
dimX <- dim.def.ncdf("Long","meters", LonVector)
```

```

dimY <- dim.def.ncdf("Lat","meters", LatVector)
dimT <- dim.def.ncdf("Time","seconds", ts, unlim=TRUE)

# create a list of netcdf variable definitions
var_list <- list()
for( item in 1:length(VARS)) {
  var_list[item] <- list(var.def.ncdf( VARS[item], "", list(dimX,dimY,dimT), MISSING_VALUE))
}

# create the file
nc <- create.ncdf(nc_output_path, var_list)

# add the coordinate system attribute data
att.put.ncdf( nc,0,"latLonUR",c(max(LatVector),max(LonVector)))
att.put.ncdf( nc,0,"gridPointLL",c(1,1))
att.put.ncdf( nc,0,"gridPointUR",c(as.numeric(length(LatVector)),as.numeric(length(LonVector))))
att.put.ncdf( nc,0,"projectionType","MERCATOR")
att.put.ncdf( nc,0,"lonCenter",-123)
att.put.ncdf( nc,0,"GridSize",c(as.numeric(length(LonVector)),as.numeric(length(LatVector))))

# iterate time and vars to put to file
tIndex <- 1
for(xTime in 1:length(timeStamps)) {
  cat(" [+] Time Index: ", tIndex," \n")
  for(var in 1:length(VARS)) {
    time<-timeStamps[xTime]
    var_name <-VARS[var]
    var_pre <-varPrefix[var]
    PATH <- paste( DIR_PATH, '/',var_name,'/', var_pre , time, sep="" )
    put.var.ncdf(nc, var_name, t(as.matrix( raster(PATH))), start=c(1,1,tIndex), count=c(-1,-1,1), FALSE)
  }
  tIndex<-tIndex+1
}

# close the file
close.ncdf(nc)

```